Atomic Energy Control Board
P.O. Box 1046
Ottawa, Canada
K1P 5S9

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DISSOLUTION RATES OF HIGH GRADE URANIUM ORE DUST FROM SASKATCHEWAN

by

R. Robertson
Becquerel Laboratories Inc.

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Research report

DISSOLUTION RATES OF HIGH GRADE URANIUM ORE DUST FROM SASKATCHEWAN

Experimental work carried out and report prepared by R. Robertson, Becquerel Laboratories Inc. under contract to the Atomic Energy Control Board.

ABSTRACT

The solubility extractions of the radionuclides U-238, Th-230, Ra-226 and Pb-210 into simulated lung fluid from artificially generated aerosols of Saskatchewan ore dust comprising approximately 40% uranium have been studied. The extraction methodology used was a continuous flow process.

Three particle size fractions of the ore were examined; they were < 3 micron, 3-7 micron and 7-21 micron. Each was subjected in duplicate to extractions with lung fluid at 37°C in the pH range 7.2-7.6. In each of the 6 extraction experiments, 10 lung fluid fractions were collected at the following time intervals: 0-2 hours, 2-4 hours, 4-8 hours, 8-16 hours, 16-24 hours, 24-48 hours, 48-72 hours, 72-144 hours, 144-240 hours, and 240-480 hours.

Each lung fluid fraction was analysed for each of the 4 radionuclides of interest. The observed cumulative extractions lay in the following ranges: U-238 11-26%, Th-230 0.5-6.4%, Ra-226 5-13% and Pb-210 9-17%.

There was no discernible correlation between the extraction rate of any of the nuclides studied and the particle size fraction of the ore. The data indicate that co-precipitation with other hydroxide forming species leached from the ore (eg. aluminum and iron) may be a strong factor in the inhibition of Th-230 extraction.

RÉSUMÉ

Des études ont été menées sur l'extraction de radionucléides, pour en déterminer la solubilité, à savoir l'uranium 238, le thorium 230, le radium 226 et le plomb 210, qui sont contenus dans un fluide pulmonaire simulé et proviennent d'aérosols artificiels de poussière de minerai de la Saskatchewan renfermant environ 40 % d'uranium. La méthode d'extraction utilisée a été un procédé d'écoulement continu.

Trois grosseurs de particules de minerai ont été examinées, c'est-à-dire < 3 microns, de 3 à 7 microns, de 7 à 21 microns. Chacune des grosseurs a fait l'objet de doubles extractions dans un fluide pulmonaire à 37° C et avec un pH variant de 7,2 à 7,6. Durant chacune des six expériences d'extraction, 10 fractions de fluide pulmonaire ont été prélevées aux intervalles suivants : 0 à 2 heures, 2 à 4 heures, 4 à 8 heures, 8 à 16 heures, 16 à 24 heures, 24 à 48 heures, 48 à 72 heures, 72 à 144 heures, 144 à 240 heures et 240 à 480 heures.

Chacune des fractions de fluide pulmonaire a été analysée pour les quatre radionucléides en question. Les extractions cumulatives observées variaient selon les taux suivants : l'uranium 238 de 11 à 26 %, le thorium 230 de 0,5 à 6,4 %, le radium 226 de 5 à 13 % et le plomb 210 de 9 à 17 %.

Il n'y avait aucun lien discernable entre le taux d'extraction de tous les radionucléides examinés et la grosseur de la particule de minerai. Les données révèlent que la co-précipitation avec d'autres espèces formant des hydroxides qui sont créées par suite de la lixiviation du minerai (p. ex. l'aluminium et le fer) peut avoir été un important facteur nuisant à l'extraction du thorium 230.

ACKNOWLEDGEMENT

The most valuable assistance of Mr. S. Jones in the experimental work and in the preparation of this report is gratefully acknowledged.

DISCLAIMER

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A. INTRODUCTION

The AECB requires data on which to base lung dosimetry calculations in connection with aerosols generated in workplaces during the processing of high-grade uranium ore from northern Saskatchewan. The work reported here represents part of the effort being applied to gaining information on the solubility component of the associated lung dosimetry model.

The results of this work will be of direct application in a parallel AECB research project entitled "Study of the Health Effects of Inhaled Uranium Ore Dust" (84.8.11/3.101.1).

B. SAMPLES PROCESSED

Appropriate samples of high-grade northern Saskatchewan uranium ore dust on filters were supplied by MacLaren Plansearch Inc. Data on these samples are given in Table 1. The samples were obtained in a laboratory fumehood via redispersion of bulk ore dust material obtained from Amok Ltd. at the inlet of a particle size fractionating cascade impactor device. Sampling times were on the order of a few minutes.

Referring to Table 1, only those samples designated B, C or D (<21 micron) were considered as bearing inhalable particles and subjected to extraction experiments. Filter Group 4 was used for Experiment no. 1 and Group 1 for Experiment no. 2.

Group 3 was used for non-destructive gamma-ray spectrometry measurements of the radionuclide concentrations. These data are presented in Appendix A.

Filter Group 2 was used in an initial extraction experiment which was aborted 8 hours into the run because of a technical problem outlined in Section C of this report. This aborted experiment, for the record designated here as Experiment no. 0, yielded little useful solubility data and the few data obtained from it are not presented in this report.

C. EXTRACTION EQUIPMENT AND PROCEDURES

The extraction equipment and procedures used were almost identical to those developed in a prior feasibility study and are fully described in the associated report[1]. A small modification to the equipment was made for the present work after an initial experiment had to be aborted because of glass fibre blockage of the thin tygon tubing line and luer fittings between the extraction vessel and the downstream membrane filter unit. This section of line was shortened and replaced by larger gauge tubing and fittings. Refer to Figure 1 for a schematic representation of the modified equipment.

The formulation used for simulated lung fluid preparation is given in Appendix F.

D. SUMMARY OF RESULTS AND DISCUSSION

1. General Remarks

The most remarkable feature of the analytical data presented below and in the tables is the poor reproducibility of the extraction data between Experiments 1 and 2. The discrepancy is much greater than can be explained by analytical imprecisions and points to important but as yet unidentified variables in the system which have not been sufficiently controlled.

A second unexpected feature of the data is the apparent lack of correlation between the solubility rates of the radionuclides of interest and the particle sizes of the ore samples. This might warrant a second look at the ore dust sampling procedures with a view to obtaining information on the degree to which particle agglomeration plays a role in distorting proper particle size fractionation.

Despite the imprecision of the data, the general conclusion can be drawn that U-238, Ra-226 and Pb-210 are substantially extracted from this type of uranium ore sample under the conditions used over the 20 day time period of the experiments. Thorium-230 is extracted to a lesser extent.

It is noted here that the methods used to analyse ore samples and lung fluid fractions are fully described in reference 1. An exception is an alpha-spectrometry method for Ra-226 which is described here in Appendix D.

2. Uranium-238 Extraction

Cumulative extraction data for U-238 are presented in Table 2. The underlying analytical data obtained by neutron activation analysis for uranium in individual lung fluid fractions are given in Appendix B.

Extractions for U-238 lie in the range 11-26% with a mean of 17.5%. Of the species studied, U-238 is extracted to the greatest extent. This is presumably a reflection of the active transport mechanism afforded by the complexing action of the carbonate ion in lung fluid.

3. Thorium-230 Extraction

Cumulative extraction data for Th-230 are presented in Table 3. The underlying analytical data for individual lung fluid fractions obtained by alpha-spectrometry are given in Appendix C.

Extractions for Th-230 lie in the range 0.5-6.5% with a mean of 2.9%. Of the species studied, Th-230 is extracted to the smallest extent. The percentage extraction tends to increase with decreasing mass of the subject ore sample. This is evidence in support of the argument that coprecipitation on other hydroxide forming species such as aluminum and iron leached from the ore plays a significant role in the relatively low solubility rate observed for Th-230 in the sort of experiment reported

here. In the lung, where ore material would normally tend to be much more widely dispersed, such coprecipitation may not be a significant factor in inhibiting Th-230 solubility and its in-vivo solubility rate may be much more in line with those for the other radionuclides studied in this work.

4. Radium-226 Extraction

Cumulative extraction data for Ra-226 are presented in Table 4. The underlying analytical data for individual lung f id fractions obtained by alpha-spectrometry are given in Appendix D.

Extractions for Ra-226 lie in the range 5-13% with a mean of 8.7%. Ra-226 exhibits behaviour between those of U-238 and Th-230. This can be rationalized by the lack of an active transport mechanism for radium on the one hand, and a positive but reduced tendency to coprecipitate with hydroxides on the other.

5. Lead-210 Extraction

Cumulative extraction data for Pb-210 are presented in Table 5. The underlying analytical data for individual lung fraction obtained by beta-counting are given in Appendix E.

Extractions for Pb-210 lie in the range 9-17% with a mean of 12%. Pb-210 exhibits behaviour between those of U-238 and Th-230, as does Ra-226. The solubility rate of Pb-210 appears to be slightly higher than that of Ra-226, which is surprising because Pb-210 would be expected to display co-precipitation behaviour on hydroxides between those displayed by thorium and radium. However, the difference in behaviour between Pb-210 and Ra-226 may not be statistically significant.

E. CLOSING REMARKS

The results with regard to U-238 and Ra-226 are substantially what might have been expected from work with uranium ores carried out in the feasibility study described in reference 1. The solubilities of Th-230 and Pb-210 are greater than expected and suggest that inhibition of extraction caused by coprecipitation was a problem with the feasibility work where gram quantities of ore test material were the norm. The results also tend to suggest the convergence of solubility rates towards the rate for uranium for all the nuclides studied as the absolute amount of ore material in the system decreases.

The poor reproducibility of the data is of concern. Some light may be shed upon this in Phase 1 of a more comprehensive study now under way[2].

F. FIGURES AND TABLES

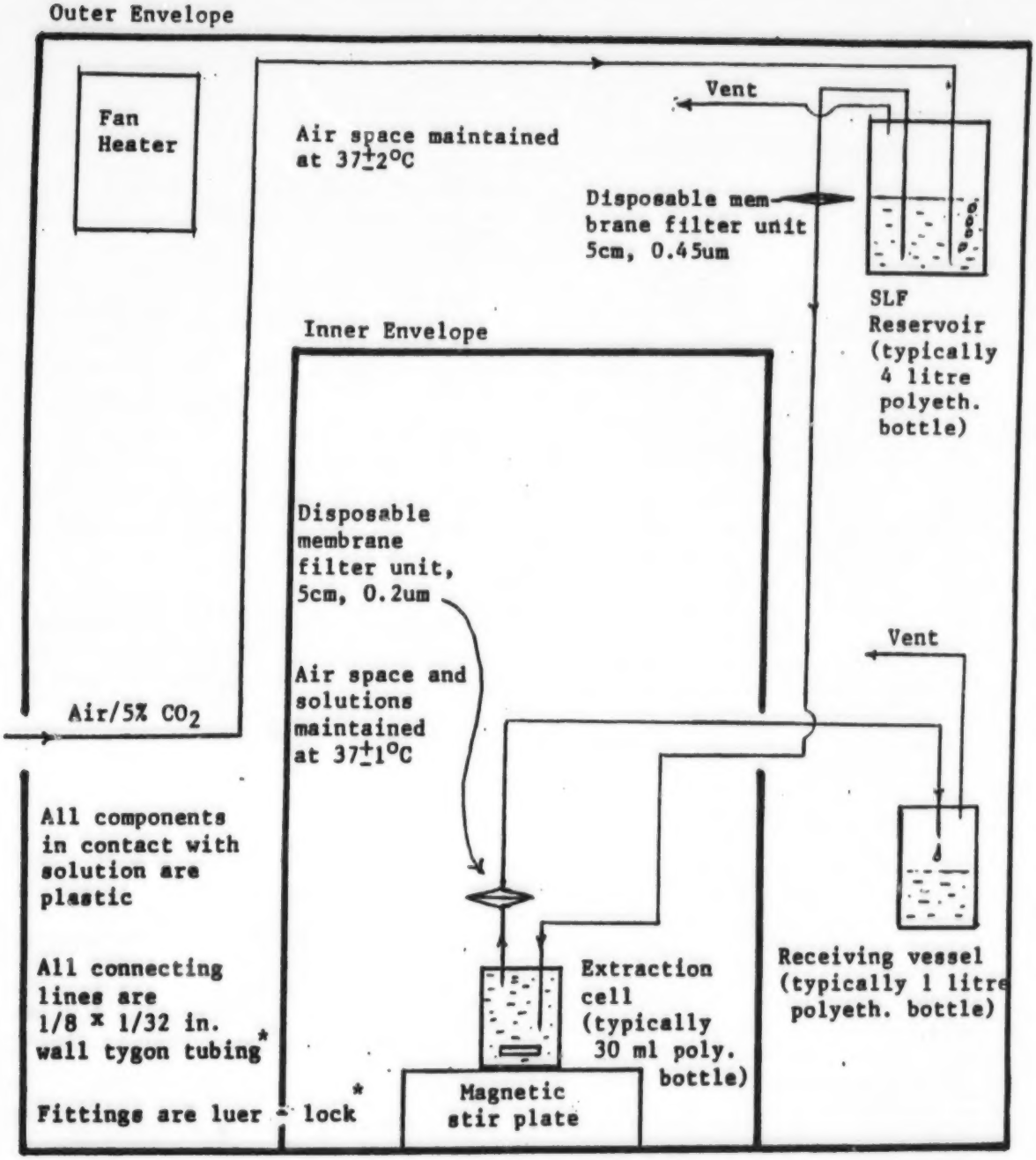
Outer Envelope
Fan Heater
Air space maintained at 37±2°C
Vent
Disposable membrane filter unit 5cm, 0.45um
SLF Reservoir (typically 4 litre polyeth. bottle)
Inner Envelope
Disposable membrane filter unit, 5cm, 0.2um
Air space and solutions maintained at 37±1°C
Vent
Air/5% CO_2
All components in contact with solution are plastic
All connecting lines are 1/8 x 1/32 in. wall tygon tubing*
Fittings are luer lock*
Extraction cell (typically 30 ml poly. bottle)
Magnetic stir plate
Receiving vessel (typically 1 litre polyeth. bottle)

FIGURE 1: Schematic Representation of Extraction Equipment

* Except between the extraction cell and the downstream membrane filter. These components were connected with 1/4 in. tygon tubing and plastic hose fittings to avoid blockage with glass fibres.

Table 1:

MacLaren Plansearch

Project - Dissolution Rates Of High Grade Uranium Ore Dust

Summary Of The Mass Loadings Of The Original Samples
Sampled at Becquerel Lab - October 2, 1987

Sample #	Size Fraction (um)	Initial Weight (mg)	Final Weight (mg)	Mass Loading (mg)
1A	> 21	16.47	80.18	63.71
1B	7 - 21	16.94	28.65	11.71
1C	3 - 7	17.48	19.62	2.14
1D	< 3	115.04	117.98	2.94
2A	> 21	16.91	49.98	33.07
2B	7 - 21	17.67	28.06	10.39
2C	3 - 7	16.04	19.51	3.47
2D	< 3	118.22	122.31	4.09
3A	> 21	17.09	46.89	29.8
3B	7 - 21	16.86	33.58	16.72
3C	3 - 7	16.07	19.73	3.66
3D	< 3	119.38	123.64	4.26
4A	> 21	16.45	45.78	29.33
4B	7 - 21	18.32	33.64	15.32
4C	3 - 7	17.71	22.18	4.47
4D	< 3	116.11	120.18	4.07

Impactor stages A, B, and C were 18 mm. glass fibre surfaces, 47 mm. glass fibre filters were used for stage D.

All weights are based on an average of at least three measurements.

Table 2: Summary of uranium extractions

Experiment no. 1

	Filter 4B 7-21 micron 44.7 % U 15.3 mg ore 6840 ug U		Filter 4C 3-7 micron 41.5 % U 4.47 mg ore 1855 ug U		Filter 4D < 3 micron 37.8 % U 4.07 mg ore 1538 ug U	
Extraction period (hours)	CUMULATIVE EXTRACTION (ug U)	(% U)	(ug U)	(% U)	(ug U)	(% U)
2	127	2	62	3	41	3
4	175	3	76	4	55	4
8	256	4	112	6	92	6
16	397	6	180	10	160	10
24	454	7	209	11	195	13
48	508	7	254	14	230	15
72	526	8	260	14	234	15
144	583	9	265	14	238	15
240	684	10	277	15	240	16
480	1204 ug	18 %	362 ug	20 %	249 ug	16 %

Experiment no. 2

	Filter 1B 7-21 micron 44.7 % U 11.71 mg ore 5230 ug U		Filter 1C 3-7 micron 41.5 % U 2.14 mg ore 888 ug U		Filter 1D < 3 micron 37.8 % U 2.94 mg ore 1110 ug U	
Extraction period (hours)	CUMULATIVE EXTRACTION (ug U)	(% U)	(ug U)	(% U)	(ug U)	(% U)
2	62	1	39.0	4	15	1
4	104	2	58.5	7	23.4	2
8	146	3	74.7	8	34.8	3
16	213	4	89.9	10	51.2	5
24	258	5	114	13	59.7	5
48	340	7	146	16	76.3	7
72	421	8	159	18	91.2	8
144	512	10	174	20	100.7	9
240	592	11	203	23	114	10
480	713 ug	14 %	230 ug	26 %	122 ug	11 %

Table 3: Summary of thorium-230 extractions

Experiment no. 1

	Filter 4B 7-21 micron 5310 Bq/g 15.3 mg ore 81.2 Bq Th-230		Filter 4C 3-7 micron 5030 Bq/g 4.47 mg ore 22.5 Bq Th-230		Filter 4D < 3 micron 4620 Bq/g 4.07 mg ore 18.8 Bq Th-230	
Extraction period (hours)	CUMULATIVE EXTRACTION (Bq Th-230)	(% Th-230)	(Bq Th-230)	(% Th-230)	(Bq Th-230)	(% Th-230)
2	0.157	0.19	0.157	0.70	0.096	0.51
4	0.188	0.23	0.182	0.81	0.114	0.61
8	0.236	0.29	0.575	2.57	0.129	0.69
16	0.316	0.39	0.634	2.83	0.156	0.83
24	0.360	0.44	0.662	2.96	0.180	0.96
48	0.374	0.46	0.691	3.08	0.251	1.34
72	0.387	0.48	0.693	3.09	0.348	1.85
144	0.393	0.48	0.708	3.16	0.372	1.98
240	0.413	0.51	0.714	3.19	0.468	2.49
480	0.448 Bq	0.55 %	0.729 Bq	3.25 %	0.527 Bq	2.80 %

Experiment no. 2

	Filter 1B 7-21 micron 5310 Bq/g 11.71 mg ore 62.1 Bq Th-230		Filter 1C 3-7 micron 5030 Bq/g 2.14 mg ore 10.8 Bq Th-230		Filter 1D < 3 micron 4620 Bq/g 2.94 mg ore 13.6 Bq Th-230	
Extraction period (hours)	CUMULATIVE EXTRACTION (Bq Th-230)	(% Th-230)	(Bq Th-230)	(% Th-230)	(Bq Th-230)	(% Th-230)
2	0.032	0.05	0.210	1.9	0.028	0.20
4	0.088	0.14	0.302	2.8	0.076	0.56
8	0.135	0.22	0.344	3.2	0.130	0.96
16	0.243	0.39	0.382	3.5	0.191	1.4
24	0.281	0.45	0.428	4.0	0.278	2.0
48	0.334	0.54	0.534	4.9	0.293	2.2
72	0.389	0.63	0.569	5.3	0.351	2.6
144	0.447	0.72	0.611	5.7	0.410	3.0
240	0.486	0.78	0.652	6.0	0.452	3.3
480	0.517 Bq	0.83 %	0.693 Bq	6.4 %	0.506 Bq	3.7 %

Table 4: Summary of radium-226 extractions

Experiment no. 1

	Filter 4B 7-21 micron 5120 Bq/g 15.3 mg ore 78.3 Bq Ra-226		Filter 4C 3-7 micron 4940 Bq/g 4.47 mg ore 22.1 Bq Ra-226		Filter 4D < 3 micron 4580 Bq/g 4.07 mg ore 18.6 Bq Ra-226	
Extraction period (hours)	CUMULATIVE EXTRACTION (Bq Ra-230)	(% Ra-226)	(Bq Ra-226)	(% Ra-226)	(Bq Ra-226)	(% Ra-226)
2	2.45	3	0.49	2	0.30	2
4	3.53	5	0.64	3	0.35	2
8	4.67	6	0.74	3	0.53	3
16	6.04	8	0.94	4	0.70	4
24	6.65	8	1.14	5	0.92	5
48	7.30	9	1.33	6	1.04	6
72	7.65	10	1.40	6	1.09	6
144	8.13	10	1.47	7	1.15	6
240	8.52	11	1.50	7	1.16	6
480	10.22 Bq	13 %	1.78 Bq	8 %	1.21 Bq	7 %

Experiment no. 2

	Filter 1B 7-21 micron 5120 Bq/g 11.71 mg ore 60.0 Bq Ra-226		Filter 1C 3-7 micron 4940 Bq/g 2.14 mg ore 10.6 Bq Ra-226		Filter 1D < 3 micron 4580 Bq/g 2.94 mg ore 13.5 Bq Ra-226	
Extraction period (hours)	CUMULATIVE EXTRACTION (Bq Ra-230)	(% Ra-226)	(Bq Ra-226)	(% Ra-226)	(Bq Ra-226)	(% Ra-226)
2	1.53	3	0.36	3	0.30	2
4	1.98	3	0.49	5	0.36	3
8	2.28	4	0.62	6	0.40	3
16	2.57	4	0.67	6	0.46	3
24	2.79	5	0.80	8	0.51	4
48	3.33	6	0.89	8	0.54	4
72	3.72	6	0.91	9	0.57	4
144	4.32	7	1.00	9	0.61	5
240	4.71	8	1.06	10	0.66	5
480	4.87 Bq	8 %	1.12 Bq	11 %	0.72 Bq	5 %

Table 5: Summary of lead-210 extractions

Experiment no. 1

	Filter 4B 7-21 micron 5730 Bq/g 15.3 mg ore 87.7 Bq Pb-210		Filter 4C 3-7 micron 5850 Bq/g 4.47 mg ore 26.1 Bq Pb-210		Filter 4D < 3 micron 5000 Bq/g 4.07 mg ore 20.4 Bq Pb-210	
Extraction period (hours)	CUMULATIVE EXTRACTION (Bq Pb-210)	(% Pb-210)	(Bq Pb-210)	(% Pb-210)	(Bq Pb-210)	(% Pb-210)
2	1.42	2	0.68	3	0.87	4
4	2.37	3	0.86	3	0.99	5
8	2.92	3	0.96	4	1.27	6
16	3.85	4	1.14	4	1.76	9
24	4.54	5	1.42	5	2.59	13
48	5.26	6	1.90	7	3.30	16
72	5.61	6	2.02	8	3.35	16
144	5.77	7	2.11	8	3.39	17
240	6.04	7	2.20	8	3.44	17
480	9.33 Bq	11 %	2.48 Bq	9.5 %	3.54 Bq	17 %

Experiment no. 2

	Filter 1B 7-21 micron 5730 Bq/g 11.71 mg ore 67.0 Bq Pb-210		Filter 1C 3-7 micron 5850 Bq/g 2.14 mg ore 12.5 Bq Pb-210		Filter 1D < 3 micron 5000 Bq/g 2.94 mg ore 14.7 Bq Pb-210	
Extraction period (hours)	CUMULATIVE EXTRACTION (Bq Pb-210)	(% Pb-210)	(Bq Pb-210)	(% Pb-210)	(Bq Pb-210)	(% Pb-210)
2	0.18	< 1	0.64	5	0.41	3
4	0.87	1	0.99	8	0.76	5
8	1.60	2	1.11	9	0.86	6
16	2.78	4	1.21	10	0.97	7
24	3.37	5	1.28	10	1.13	8
48	4.39	7	1.38	11	1.20	8
72	5.46	8	1.46	12	1.27	9
144	6.46	10	1.52	12	1.32	9
240	7.28	11	1.63	13	1.38	9
480	7.90 Bq	12 %	1.69 Bq	14 %	1.44 Bq	10 %

REFERENCES

1. Robertson, R. Feasibility Study of the Dissolution Rates of Uranium Ore Dust, Uranium Concentrates and Uranium Compounds in Simulated Lung Fluid, AECB Report no. INFO 205, 1986 July.

2. Physical Characteristics and Solubility of Long-Lived Airborne Particulates in Uranium Producing and Manufacturing Facilities; Supply and Services Canada contract 87055-7-4028/01-SS with MacLaren Plansearch Inc. issued March 1988.

APPENDIX A

ANALYSIS RESULTS: GAMMA-RAY SPECTROMETRY OF HIGH GRADE URANIUM ORE FROM SASKATCHEWAN.

BECQUEREL LABORATORIES INC.

REPORT ON RADIONUCLIDES OF INTEREST IN SOLID SAMPLES AS DETERMINED BY DIRECT GAMMA-RAY SPECTROMETRY.

SAMPLES OF APPROX. 1G WHICH ARE DOUBLY ENCAPSULATED IN 2 MIL LAY-FLAT POLYETHYLENE BAGS ARE COUNTED ON THE SURFACE OF A GERMANIUM DETECTOR.

MATERIAL: HIGH GRADE U ORE #3A >21 MICRON

SAMPLE MASS: .0298 GRAMS

COUNT PERIOD: 17972 SECONDS

COUNT DAY: 330 JULIAN 1987

(NOTE THAT MINUS SIGNS INDICATE 'LESS THAN' VALUES)

URANIUM-238 ESTIMATE

VIA TH-234(63.3KEV)	5320	BQ/G	RSD=5 %

THORIUM-230 ESTIMATE

VIA TH-230(67.7KEV)	5720	BQ/G	RSD=16.3 %

RADIUM-226 ESTIMATE

VIA RA-226(186.2KEV)	4740	BQ/G	RSD=4.9 %

LEAD-210 ESTIMATE

VIA PB-210(46.5KEV)	5090	BQ/G	RSD=5.4 %

RADIUM-228 ESTIMATES

VIA AC-228(911.1KEV)	-45.4	BQ/G	RSD=0 %
VIA AC-228(969.1KEV)	-76	BQ/G	RSD=0 %

THORIUM-228 ESTIMATES

VIA PB-212(238.6KEV)	-11.2	BQ/G	RSD=0 %
VIA TL-208(583.1KEV)	-35.3	BQ/G	RSD=0 %

SUMMARY OF PREFERRED VALUES CALCULATED FROM ABOVE ESTIMATES

URANIUM-238	5320	BQ/G	RSD=5 %
THORIUM-230	5720	BQ/G	RSD=16.3 %
RADIUM-226	4740	BQ/G	RSD=4.9 %
LEAD-210	5090	BQ/G	RSD=5.4 %
RADIUM-228	-45.4	BQ/G	RSD=0 %
THORIUM-228	-11.2	BQ/G	RSD=0 %
URANIUM CONCENTRATION ASSUMING NATURAL ISOTOPE RATIOS:			
FROM U-238	433000	PPM	RSD=5 %

BECQUEREL LABORATORIES INC.

REPORT ON RADIONUCLIDES OF INTEREST IN SOLID SAMPLES AS DETERMINED BY DIRECT GAMMA-RAY SPECTROMETRY.

SAMPLES OF APPROX. 1G WHICH ARE DOUBLY ENCAPSULATED IN 2 MIL LAY-FLAT POLYETHYLENE BAGS ARE COUNTED ON THE SURFACE OF A GERMANIUM DETECTOR.

MATERIAL: HIGH GRADE U ORE #3B 7-21 MICRON

SAMPLE MASS: .01672 GRAMS

COUNT PERIOD: 10849 SECONDS

COUNT DAY: 328 JULIAN 1987

(NOTE THAT MINUS SIGNS INDICATE 'LESS THAN' VALUES)

URANIUM-238 ESTIMATE

VIA TH-234(63.3KEV)	5500	BQ/G	RSD=6.5 %

THORIUM-230 ESTIMATE

VIA TH-230(67.7KEV)	-3790	BQ/G	RSD=0 %

RADIUM-226 ESTIMATE

VIA RA-226(186.2KEV)	5120	BQ/G	RSD=6.2 %

LEAD-210 ESTIMATE

VIA PB-210(46.5KEV)	5730	BQ/G	RSD=6.9 %

RADIUM-228 ESTIMATES

VIA AC-228(911.1KEV)	-80.6	BQ/G	RSD=0 %
VIA AC-228(969.1KEV)	-149	BQ/G	RSD=0 %

THORIUM-228 ESTIMATES

VIA PB-212(238.6KEV)	-20.6	BQ/G	RSD=0 %
VIA TL-208(583.1KEV)	-67.8	BQ/G	RSD=0 %

SUMMARY OF PREFERRED VALUES CALCULATED FROM ABOVE ESTIMATES

URANIUM-238	5500	BQ/G	RSD=6.5 %
THORIUM-230	-3790	BQ/G	RSD=0 %
RADIUM-226	5120	BQ/G	RSD=6.2 %
LEAD-210	5730	BQ/G	RSD=6.9 %
RADIUM-228	-80.6	BQ/G	RSD=0 %
THORIUM-228	-20.6	BQ/G	RSD=0 %

URANIUM CONCENTRATION ASSUMING NATURAL ISOTOPE RATIOS:

FROM U-238	447000	PPM	RSD=6.5 %

BECQUEREL LABORATORIES INC.

REPORT ON RADIONUCLIDES OF INTEREST IN SOLID SAMPLES AS DETERMINED BY DIRECT GAMMA-RAY SPECTROMETRY.

SAMPLES OF APPROX. 1G WHICH ARE DOUBLY ENCAPSULATED IN 2 MIL LAY-FLAT POLYETHYLENE BAGS ARE COUNTED ON THE SURFACE OF A GERMANIUM DETECTOR.

MATERIAL: HIGH GRADE U ORE #3C 3-7 MICRON

SAMPLE MASS: 3.66000E-03 GRAMS

COUNT PERIOD: 35986 SECONDS

COUNT DAY: 327 JULIAN 1987

(NOTE THAT MINUS SIGNS INDICATE 'LESS THAN' VALUES)

URANIUM-238 ESTIMATE

VIA TH-234(63.3KEV)	5110	BQ/G	RSD=7.4 %

THORIUM-230 ESTIMATE

VIA TH-230(67.7KEV)	6830	BQ/G	RSD=26.9 %

RADIUM-226 ESTIMATE

VIA RA-226(186.2KEV)	4940	BQ/G	RSD=7.1 %

LEAD-210 ESTIMATE

VIA PB-210(46.5KEV)	5850	BQ/G	RSD=7.7 %

RADIUM-228 ESTIMATES

VIA AC-228(911.1KEV)	-127	BQ/G	RSD=0 %
VIA AC-228(969.1KEV)	-213	BQ/G	RSD=0 %

THORIUM-228 ESTIMATES

VIA PB-212(238.6KEV)	-30.1	BQ/G	RSD=0 %
VIA TL-208(583.1KEV)	-92.4	BQ/G	RSD=0 %

SUMMARY OF PREFERRED VALUES CALCULATED FROM ABOVE ESTIMATES

URANIUM-238	5110	BQ/G	RSD=7.4 %
THORIUM-230	6830	BQ/G	RSD=26.9 %
RADIUM-226	4940	BQ/G	RSD=7.1 %
LEAD-210	5850	BQ/G	RSD=7.7 %
RADIUM-228	-127	BQ/G	RSD=0 %
THORIUM-228	-30.1	BQ/G	RSD=0 %

URANIUM CONCENTRATION ASSUMING NATURAL ISOTOPE RATIOS:

FROM U-238	415000	PPM	RSD=7.4 %

BECQUEREL LABORATORIES INC.

REPORT ON RADIONUCLIDES OF INTEREST IN SOLID SAMPLES AS DETERMINED BY DIRECT GAMMA-RAY SPECTROMETRY.

SAMPLES OF APPROX. 1G WHICH ARE DOUBLY ENCAPSULATED IN 2 MIL LAY-FLAT POLYETHYLENE BAGS ARE COUNTED ON THE SURFACE OF A GERMANIUM DETECTOR.

MATERIAL: HIGH GRADE U ORE #3D <3 MICRON

SAMPLE MASS: 4.26000E-03 GRAMS

COUNT PERIOD: 50379 SECONDS

COUNT DAY: 330 JULIAN 1987

(NOTE THAT MINUS SIGNS INDICATE 'LESS THAN' VALUES)

URANIUM-238 ESTIMATE

VIA TH-234(63.3KEV)	4650	BQ/G	RSD=6.7 %

THORIUM-230 ESTIMATE

VIA TH-230(67.7KEV)	4810	BQ/G	RSD=28.6 %

RADIUM-226 ESTIMATE

VIA RA-226(186.2KEV)	4580	BQ/G	RSD=6.3 %

LEAD-210 ESTIMATE

VIA PB-210(46.5KEV)	5000	BQ/G	RSD=7.1 %

RADIUM-228 ESTIMATES

VIA AC-228(911.1KEV)	-92.5	BQ/G	RSD=0 %
VIA AC-228(969.1KEV)	-161	BQ/G	RSD=0 %

THORIUM-228 ESTIMATES

VIA PB-212(238.6KEV)	-22.6	BQ/G	RSD=0 %
VIA TL-208(583.1KEV)	-68.5	BQ/G	RSD=0 %

SUMMARY OF PREFERRED VALUES CALCULATED FROM ABOVE ESTIMATES

URANIUM-238	4650	BQ/G	RSD=6.7 %
THORIUM-230	4810	BQ/G	RSD=28.6 %
RADIUM-226	4580	BQ/G	RSD=6.3 %
LEAD-210	5000	BQ/G	RSD=7.1 %
RADIUM-228	-92.5	BQ/G	RSD=0 %
THORIUM-228	-22.6	BQ/G	RSD=0 %
URANIUM CONCENTRATION ASSUMING NATURAL ISOTOPE RATIOS: FROM U-238	378000	PPM	RSD=6.7 %

BECQUEREL LABORATORIES INC.

REPORT ON RADIONUCLIDES OF INTEREST IN SOLID SAMPLES AS DETERMINED BY DIRECT GAMMA-RAY SPECTROMETRY.

SAMPLES OF APPROX. 1G WHICH ARE DOUBLY ENCAPSULATED IN 2 MIL LAY-FLAT POLYETHYLENE BAGS ARE COUNTED ON THE SURFACE OF A GERMANIUM DETECTOR.

MATERIAL: BL5 ON 25MM FILTER
SAMPLE MASS: .051 GRAMS
COUNT PERIOD: 21579 SECONDS
COUNT DAY: 327 JULIAN 1987

(NOTE THAT MINUS SIGNS INDICATE 'LESS THAN' VALUES)

URANIUM-238 ESTIMATE

VIA TH-234(63.3KEV)	840	BQ/G	RSD=6.7 %

THORIUM-230 ESTIMATE

VIA TH-230(67.7KEV)	1020	BQ/G	RSD=24.8 %

RADIUM-226 ESTIMATE

VIA RA-226(186.2KEV)	779	BQ/G	RSD=6.4 %

LEAD-210 ESTIMATE

VIA PB-210(46.5KEV)	811	BQ/G	RSD=7.4 %

RADIUM-228 ESTIMATES

VIA AC-228(911.1KEV)	-14.7	BQ/G	RSD=0 %
VIA AC-228(969.1KEV)	-25.1	BQ/G	RSD=0 %

THORIUM-228 ESTIMATES

VIA PB-212(238.6KEV)	-3.68	BQ/G	RSD=0 %
VIA TL-208(583.1KEV)	-11.7	BQ/G	RSD=0 %

SUMMARY OF PREFERRED VALUES CALCULATED FROM ABOVE ESTIMATES

URANIUM-238	840	BQ/G	RSD=6.7 %
THORIUM-230	1020	BQ/G	RSD=24.8 %
RADIUM-226	779	BQ/G	RSD=6.4 %
LEAD-210	811	BQ/G	RSD=7.4 %
RADIUM-228	-14.7	BQ/G	RSD=0 %
THORIUM-228	-3.68	BQ/G	RSD=0 %

URANIUM CONCENTRATION ASSUMING NATURAL ISOTOPE RATIOS:

FROM U-238	68300	PPM	RSD=6.7 %

BECQUEREL LABORATORIES INC.

REPORT ON RADIONUCLIDES OF INTEREST IN SOLID SAMPLES AS DETERMINED BY DIRECT GAMMA-RAY SPECTROMETRY.

SAMPLES OF APPROX. 1G WHICH ARE DOUBLY ENCAPSULATED IN 2 MIL LAY-FLAT POLYETHYLENE BAGS ARE COUNTED ON THE SURFACE OF A GERMANIUM DETECTOR.

MATERIAL: BL5 ON 47MM FILTER

SAMPLE MASS: .139 GRAMS

COUNT PERIOD: 16182 SECONDS

COUNT DAY: 327 JULIAN 1987

(NOTE THAT MINUS SIGNS INDICATE 'LESS THAN' VALUES)

URANIUM-238 ESTIMATE

VIA TH-234(63.3KEV)	873	BQ/G	RSD=5.3 %

THORIUM-230 ESTIMATE

VIA TH-230(67.7KEV)	751	BQ/G	RSD=22.1 %

RADIUM-226 ESTIMATE

VIA RA-226(186.2KEV)	668	BQ/G	RSD=5.7 %

LEAD-210 ESTIMATE

VIA PB-210(46.5KEV)	892	BQ/G	RSD=5.7 %

RADIUM-228 ESTIMATES

VIA AC-228(911.1KEV)	-9	BQ/G	RSD=0 %
VIA AC-228(969.1KEV)	-15.9	BQ/G	RSD=0 %

THORIUM-228 ESTIMATES

VIA PB-212(238.6KEV)	-2.24	BQ/G	RSD=0 %
VIA TL-208(583.1KEV)	-7.07	BQ/G	RSD=0 %

SUMMARY OF PREFERRED VALUES CALCULATED FROM ABOVE ESTIMATES

URANIUM-238	873	BQ/G	RSD=5.3 %
THORIUM-230	751	BQ/G	RSD=22.1 %
RADIUM-226	668	BQ/G	RSD=5.7 %
LEAD-210	892	BQ/G	RSD=5.7 %
RADIUM-228	-9	BQ/G	RSD=0 %
THORIUM-228	-2.24	BQ/G	RSD=0 %
URANIUM CONCENTRATION ASSUMING NATURAL ISOTOPE RATIOS: FROM U-238	71000	PPM	RSD=5.3 %

APPENDIX B

ANALYSIS RESULTS: NEUTRON ACTIVATION ANALYSIS OF LUNG FLUID FRACTIONS FOR U-238.

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 % .
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #1 FILTER 4B 7-21 MICRON U-ORE

LUNG FLUID FRACTION	S / F	U-238
1 :0-2 HOURS	21.4 / 143	127 UG (RSD=3 %)
U 2 :2-4 HOURS	23.1 / 230	48 UG (RSD=4 %)
U 3 :4-8 HOURS	26.1 / 228	81 UG (RSD=4 %)
U 4 :8-16 HOURS	26.4 / 213	141 UG (RSD=3 %)
U 5 :16-24 HOURS	25.5 / 172	57 UG (RSD=4 %)
U 6 :24-48 HOURS	51.8 / 365	54 UG (RSD=4 %)
U 7 :48-72 HOURS	48.7 / 312	18.4 UG (RSD=5 %)
U 8 :72-144 HOURS	63.3 / 450	57 UG (RSD=4 %)
U 9 :144-240 HOURS	55.7 / 430	101 UG (RSD=4 %)
U 10 :240-480 HOURS	154 / 1030	520 UG (RSD=3 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 %.
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #1 FILTER 4C 3-7 MICRON U-ORE

LUNG FLUID FRACTION	S / F	U-238
U 1 :0-2 HOURS	24.2 / 173	62 UG (RSD=4 %)
U 2 :2-4 HOURS	26.5 / 208	13.52 UG (RSD=6 %)
U 3 :4-8 HOURS	31.3 / 258	36 UG (RSD=5 %)
U 4 :8-16 HOURS	26.2 / 231	68 UG (RSD=4 %)
U 5 :16-24 HOURS	27 / 234	29 UG (RSD=5 %)
U 6 :24-48 HOURS	57.6 / 390	45 UG (RSD=4 %)
U 7 :48-72 HOURS	54.1 / 410	5.5 UG (RSD=9 %)
U 8 :72-144 HOURS	53.6 / 485	4.88 UG (RSD=11 %)
U 9 :144-240 HOURS	50.4 / 400	12.02 UG (RSD=6 %)
U 10 :240-480 HOURS	151 / 1180	85 UG (RSD=4 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 %.
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #1 FILTER 4D <3 MICRON U-ORE

LUNG FLUID FRACTION	S / F	U-238
U 1 :0-2 HOURS	25.2 / 179	41 UG (RSD=4 %)
U 2 :2-4 HOURS	27 / 189	13.66 UG (RSD=6 %)
U 3 :4-8 HOURS	29.4 / 206	37 UG (RSD=4 %)
U 4 :8-16 HOURS	26 / 222	68 UG (RSD=4 %)
U 5 :16-24 HOURS	27.7 / 237	35 UG (RSD=5 %)
U 6 :24-48 HOURS	49.3 / 440	35 UG (RSD=5 %)
U 7 :48-72 HOURS	49.5 / 304	4.2 UG (RSD=10 %)
U 8 :72-144 HOURS	54.5 / 440	3.51 UG (RSD=11 %)
U 9 :144-240 HOURS	66.9 / 570	2.25 UG (RSD=15 %)
U 10 :240-480 HOURS	150 / 1270	8.64 UG (RSD=7 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 % .
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #2 FILTER 1B 7-21 MICRON U-ORE

LUNG FLUID FRACTION	S / F	U-238
U 1 :0-2 HOURS	20.5 / 154	62 UG (RSD=4 %)
U 2 :2-4 HOURS	14.7 / 133	42 UG (RSD=4 %)
U 3 :4-8 HOURS	14.3 / 129	42 UG (RSD=4 %)
U 4 :8-16 HOURS	28.3 / 325	67 UG (RSD=4 %)
U 5 :16-24 HOURS	22.3 / 225	45 UG (RSD=4 %)
U 6 :24-48 HOURS	55.8 / 480	82 UG (RSD=4 %)
U 7 :48-72 HOURS	43.4 / 350	81 UG (RSD=4 %)
U 8 :72-144 HOURS	72.4 / 728	91 UG (RSD=4 %)
U 9 :144-240 HOURS	84.1 / 855	80 UG (RSD=4 %)
U 10 :240-480 HOURS	100 / 1290	121 UG (RSD=4 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 %.
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #2 FILTER 1C 3-7 MICRON U-ORE

LUNG FLUID FRACTION	S / F	U-238
U 11 :0-2 HOURS	16.9 / 168	39 UG (RSD=4 %)
U 12 :2-4 HOURS	14.5 / 139	19.48 UG (RSD=5 %)
U 13 :4-8 HOURS	15.5 / 151	16.21 UG (RSD=6 %)
14 :8-16 HOURS	14.4 / 129	15.2 UG (RSD=6 %)
U 15 :16-24 HOURS	20.8 / 192	24 UG (RSD=5 %)
U 16 :24-48 HOURS	54.4 / 548	32 UG (RSD=5 %)
U 17 :48-72 HOURS	30 / 300	12.72 UG (RSD=6 %)
U 18 :72-144 HOURS	50.5 / 492	15.19 UG (RSD=6 %)
U 19 :144-240 HOURS	30.9 / 270	29 UG (RSD=5 %)
U 20 :240-480 HOURS	118 / 1450	27 UG (RSD=6 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 %.
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #2 FILTER 1D <3 MICRON U-ORE

LUNG FLUID FRACTION	S / F	U-238
U 21 :0-2 HOURS	19.4 / 197	15 UG (RSD=6 %)
U 22 :2-4 HOURS	18.7 / 153	8.38 UG (RSD=7 %)
U 23 :4-8 HOURS	18.4 / 162	11.39 UG (RSD=6 %)
U 24 :8-16 HOURS	27.4 / 269	16.38 UG (RSD=6 %)
U 25 :16-24 HOURS	20.2 / 197	8.5 UG (RSD=8 %)
U 26 :24-48 HOURS	68.2 / 645	16.57 UG (RSD=6 %)
U 27 :48-72 HOURS	47.6 / 425	14.89 UG (RSD=6 %)
U 28 :72-144 HOURS	70.5 / 620	9.46 UG (RSD=7 %)
U 29 :144-240 HOURS	37.8 / 335	13.63 UG (RSD=6 %)
U 30 :240-480 HOURS	119 / 1200	8.01 UG (RSD=9 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 % .
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: EXPT. #1 BLANK

LUNG FLUID FRACTION	S / F	U-238
U 1 :0-2 HOURS	18 / 168	.72 UG (RSD=41 %)
:2-4 HOURS	18 / 119	-.45 UG (RSD=0 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 % .
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: STANDARDS AND BLANK

LUNG FLUID FRACTION	S / F	U-238
U 1 :DL-1 #1	.241 / 1	40 UG (RSD=4 %)
U 2 :DL-1 #2	.224 / 1	41 UG (RSD=4 %)
U 3 :SOLUTION STD. #1	2.197 / 1	1.25 UG (RSD=5 %)
U 4 :SOLUTION STD. #2	1.928 / 1	1.43 UG (RSD=5 %)
U 5 :BLANK	1 / 1	-.06 UG (RSD=0 %)

BECQUEREL LABORATORIES INC.
AECB PROJECT - SOLUBILITY OF MATERIALS IN SIMULATED LUNG FLUID

REPORT ON U-238 IN SIMULATED LUNG FLUID SAMPLES. MEASUREMENT VIA NEUTRON ACTIVATION ANALYSIS AFTER PRECONCENTRATION OF THE ANALYTES BY COPRECIPITATION ON ALUMINUM OXINATE.

NOTES:
RESULTS ARE MASS OF U-238 IN TOTAL SLF FRACTION.
MINUS SIGNS INDICATE 'LESS THAN' VALUES.
S/F = ANALYZED SAMPLE VOLUME / TOTAL SLF FRACTION VOLUME.
CHEMICAL YIELD FACTOR APPLIED 100 % .
RSD = RELATIVE STANDARD DEVIATION (3% + 1 SIGMA STATISTICS).

TEST MATERIAL: URANIUM STDS

LUNG FLUID FRACTION	S / F	U-238
U 31 :DL-1 #1	.518 / 1	43 UG (RSD=4 %)
U 32 :DL-1 #2	.484 / 1	42 UG (RSD=4 %)
U 33 :DL-1 #3	.516 / 1	40 UG (RSD=4 %)
34 :DL-1 #4	.479 / 1	37 UG (RSD=4 %)
U 35 :SOLN. STD #1 1.19 UG/ML	2.026 / 1	1.21 UG (RSD=5 %)
U 36 :SOLN. STD #2 1.19 UG/ML	2.047 / 1	1.18 UG (RSD=6 %)
U 37 :BLANK 100 ML DIST. WATER	1 / 1	-.05 UG (RSD=0 %)

APPENDIX C

ANALYSIS RESULTS: ALPHA SPECTROMETRY FOR Th-230 IN LUNG FLUID FRACTIONS.

	Filter 4B 7-21 micron	Filter 4C 3-7 micron	Filter 4D <3 micron
2 hours	.157 Bq	.157 Bq	.096 Bq
4	.031	.025	.018
8	.048	.393	.015
16	.080	.059	.027
24	.044	.028	.024
48	.014	.029	.071
72	.013	.015	.097
144	.006	.002	.024
240	.020	.006	.096
480	.035	.015	.059

	Filter 1B 7-21 micron	Filter 1C 3-7 micron	Filter 1D <3 micron
2 hours	.032 Bq	.210 Bq	.028 Bq
4	.056	.092	.048
8	.047	.042	.054
16	.108	.038	.061
24	.038	.046	.087
48	.053	.106	.015
72	.055	.035	.058
144	.058	.042	.059
240	.039	.041	.042
480	.031	.041	.054

APPENDIX D

ANALYSIS RESULTS: ALPHA SPECTROMETRY FOR Ra-226 IN LUNG FLUID FRACTIONS.

	Filter 4B 7-21 micron	Filter 4C 3-7 micron	Filter 4D <3 micron
2 hours	2.45 Bq	.49 Bq	.30 Bq
4	1.08	.15	.052
8	1.14	.10	.18
16	1.37	.20	.17
24	.61	.20	.22
48	.65	.19	.12
72	.35	.071	.049
144	.48	.070	.058
240	.39	.031	.012
480	1.70	.28	.051

	Filter 1B 7-21 micron	Filter 1C 3-7 micron	Filter 1D <3 micron
2 hours	1.53 Bq	.36 Bq	.30 Bq
4	.45	.13	.062
8	.30	.13	.042
16	.29	.052	.057
24	.22	.13	.050
48	.54	.090	.031
72	.39	.021	.030
144	.60	.091	.037
240	.39	.056	.051
480	.16	.060	.062

OUTLINE OF METHOD FOR DETERMINATION OF Ra-226 IN LUNG FLUID BY ALPHA-SPECTROMETRY

A few micrograms of barium ion, a few hundred milligrams of calcium ion and radium-224 tracer are added to a subsample of a lung fluid fraction. Calcium phosphate is precipitated by adding sodium hydrogen phosphate solution and adjusting the solution to pH 9 using ammonium hydroxide. The calcium phosphate gel containing coprecipitated radium is separated by centrifugation and dissolved in concentrated hydrochloric acid. The solution is adjusted in volume with water and passed over a cation exchange column which retains the radium. The column is then washed and the radium eluted finally with pH 8 ammonium citrate solution. The solution is then acidified with sulfuric acid and seeded with about 100 micrograms barium sulphate from a stock seed suspension. After stirring for about 1 hour using a magnetic stir bar, the solution is refrigerated and then the $Ba/RaSO_4$ precipitate is collected on a membrane filter for alpha-spectrometry.

APPENDIX E

ANALYSIS RESULTS: BETA COUNTING FOR Pb-210 IN LUNG FLUID FRACTIONS.

	Filter 4B 7-21 micron	Filter 4C 3-7 micron	Filter 4D <3 micron
2 hours	1.42 Bq	.68 Bq	.87 Bq
4	.95	.18	.12
8	.55	.10	.28
16	.93	.18	.49
24	.69	.28	.83
48	.72	.48	.71
72	.35	.12	.050
144	.16	.093	.043
240	.27	.089	.048
480	3.29	.28	.10

	Filter 1B 7-21 micron	Filter 1C 3-7 Micron	Filter 1D <3 micron
2 hours	.18 Bq	.64 Bq	.41 Bq
4	.69	.35	.35
8	.73	.12	.10
16	1.18	.10	.11
24	.59	.07	.16
48	1.02	.10	.07
72	1.07	.08	.07
144	1.00	.06	<.05
240	.82	.11	.06
480	.62	.06	.06

APPENDIX F

SIMULATED LUNG FLUID.

Simulated lung fluid was prepared in 10L batches by adding the ingredients listed below in order to approximately 9L distilled water in a polyethylene container. Each reagent was dissolved with stirring before the next was added. The final volume was made to be 10L with distilled water and then the solution was saturated with air/5% CO_2. Finally the solution was adjusted to pH 7.3-7.4 with small volumes of 1N HCl before being stored refrigerated.

Daily requirements were taken from this stored supply, vacuum filtered over a 47mm 0.25um membrane filter, resaturated with air/5% CO_2 and re-adjusted to pH 7.25 before use in extraction processes.

The refrigerated, stored supply of simulated lung fluid became increasingly difficult to filter with the passage of time. The typical lifetime of such a 10L supply was 1 week. Any solution older than 1 week was discarded.

Simulated lung fluid ingredients to make 10L:

	Chemical Formula	Mass	Name	Fisher Scientific Catalogue Number
1.	$MgCl_2 \cdot 6H_2O$	2.03 g	Magnesium chloride	M-33
2.	$NaCl$	60.02 g	Sodium chloride	S-271B
3.	KCl	2.98 g	Potassium chloride	P-217
4.	Na_2HPO_4	1.42 g	Sodium phosphate	S-374
5.	Na_2SO_4	0.71 g	Sodium sulphate	S-421
6.	$CaCl_2 \cdot 2H_2O$	3.68 g	Calcium chloride	C-79
7.	$NaH_3C_2O_2$	5.74 g	Sodium acetate	S-210
8.	$NaHCO_3$	26.04 g	Sodium bicarbonate	S-233B
9.	$Na_3H_3C_6O_7 \cdot 2H_2O$	0.97 g	Sodium citrate	S-279

All of the above chemicals were certified ACS grade except No. 9 which was Fisher certified.